RECOMMENDED COOLDOWN PROCEDURES

FOR

E-ZONE CRYOGENIC PIPING SYSTEMS

December 1963

AETRON
Covina, California

TABLE OF CONTENTS

I. INTRODUCTION

The purpose of this report is to recommend realistic and economical cooldown procedures for E-Zone Cryogenic Systems associated with the M-1 Engine Test Facilities under contracts NAS 8-4014 and NAS 8-4015. It is the intent at this time to establish the feasibility of a generalized procedure, not to develope detailed operational procedures. Recommendations presented here have been formulated after a comprehensive study of all available engineering reports, design calculations and technical discussions related to the physical and operational features of the E-Zone Turbo Pump Assembly Test Facilities, Test Stands E1 and E3. Operational cooldown procedures will be developed by Liquid Rocket Plant Test Division prior to and during activation of the Test Facilities.

Preliminary Aerojet-General Corporation studies which led to the development of system design criteria were supplemented by consultant contracts to Linde Company and AiResearch. During the process of design, criteria revisions were incorporated when it became apparent that unforeseen problems existed in the original system concept. As a result of constant review by Aerojet and NASA, the Cryogenic Systems now in the final phase of procurement are adaptable to the cooldown procedures here recommended.

The Cryogenic Systems in E-Zone consist in general of LH_2 and LO_2 storage facilities and small diameter transfer lines; off-stand LH_2 and LO_2 vacuum insulated run and catch vessels; on-stand LH_2 and LO_2 vacuum insulated transient run vessels supplying propellant through suction lines to the TPA positions; on-stand high pressure LH_2 and LO_2 vacuum insulated GGA run vessels; large diameter LH_2 and LO_2 run lines between off-stand and on-stand vessels; and large diameter discharge lines from the TPAs to the respective catch vessels. These systems are defined schematically by Figures 1 and 2. Cool-down procedures for the small diameter LH_2 and LO_2 piping systems fall well within the realm of competance of existing AGC/LRP operational procedures and pose no particular problems; therefore, this report will deal strictly with the basic procedures associated with the large diameter piping, the off-stand run and catch vessels and the heavy wall on-stand run vessels. All conclusions and recommendations contained herein are in agreement with studies prepared by the Computer Sciences Division at Von Karman Center, Azusa, California, and are included as Appendix A.

II. TECHNICAL DISCUSSION

Present designs for LH_2 and LO_2 piping systems have been subjected to flexibility analysis and have been determined adequate from the standpoint of contraction and expansion due to steady state thermal variations. The fact that precooling techniques are required to assist in activation of the LH_2 systems was recognized by Aerojet as early as 15 November 1962 and outlined briefly in Progress Report No. 4, Resident Contract P O A 290676; however, at that time there appeared to be several feasible methods for step cooldown of LH_2 lines to minimize LH_2 losses and transient stresses in the pipe and vessel due to high temperature gradients in the pipe or vessel walls. The most economical procedure could not be established with information then available; however, two basic approaches were considered:

1. Precool with LN_2
2. Precool with cold GN_2 or GH_2

The first approach offered a savings in LH_2; however, to effectively introduce LN_2 into the system, would add considerably to the facility cost; and proper evacuation of the LN_2 from a complicated system of piping, valves and vessels could prove costly, time consuming, and the task of determining when the LN_2/LH_2 was thoroughly evacuated would be exceedingly difficult.

In early October 1963, the decision was made to proceed with development of LH_2 system cooldown procedures in parallel with a procedure which was expected from the contractor for the LH_2 piping system. Alternate methods of cooling the LH_2 piping system to be considered were as follows:

1. Consider shocking the piping system with a fast moving front of LH_2 moving at a velocity sufficient to prevent bowing due to stratified - two-phase flow.

2. Consider applying a saturated LH_2 vapor to the piping system by establishment of atomization stations along the run of piping.

3. Consider the use of a sparging line within the large diameter vacuum insulated piping systems which would allow simultaneous injection of LH_2 in a uniform spray at many points within the system.

4. Consider precooling of the piping system with cold GH_2 to some predetermined cryogenic temperature.

Upon receipt of inconclusive recommendations for cooldown of the LH_2 piping from the system piping contractor, the parallel study by AETRON, which was supported by the Computer Sciences Division of Von Karman Center, was accelerated. A preliminary meeting was held on 22 October 1963 attended by cognizant personnel from NASA, LRP and AETRON at which time Aerojet recommended that all attention be concentrated upon establishing a cooldown procedure utilizing cold gas. The source of cold GH_2 or GO_2 gas was established as capable of being supplied from either the off-stand run or catch vessels. Aerojet further stated that alternative methods for system cooldown had been proven unfeasible due to unreasonable facility cost increases or probable over stress of system components during cooldown.

Cooldown studies by the Computer Sciences Division of Von Karman Center have been completed and have been utilized to develope the following procedures for system cooldown of LH_2 Systems, LO_2 Systems and thick walled cryogenic vessel systems.

A. LH_2 SYSTEM COOLDOWN PROCEDURES

1. Provide GN_2 purge through vessel V-E1, run line to V-E33, V-E21 and V-E9; vessels V-E33, V-E9; suction lines FTPA, GGA and the discharge line from the FTPA to vessel V-E2.

2. Sweep purge same system with warm GH_2.

3. Initiate filling of vessels V-E1 and V-E2 through previously cooled 4" diameter transfer lines. Fill with LH_2 at rate of 900# per hour for approximately one hour until steady state condition of cooldown is achieved.

4. Pressurize V-E1 or V-E2 to approximately 100 psi with liquid level at the 1/2 point and allow GH_2 gas pad to stabilize to approximately 50°R.

5. Relieve cold GH_2 through piping system either from V-E1 in the direction of normal liquid flow, or from V-E2 in the direction counter to normal liquid flow.

6. Regulate rate of gas flow with Hammel-Dahl flow control valves to provide a flow rate of 500#/hour in the reverse direction of flow or 1500#/hour in the normal direction of flow, at a maximum velocity of 50 feet/second.

7. Attain an exhaust gas temperature of 200°R at extreme end of system, after which system may undergo fill operation at normal speed.

8. Maintain LH_2 system in a chilled condition by venting boil-off gases from V-E2 thru the discharge line by passing the TPA then thru on-stand run vessels and the propellant run line to the off-stand run vessel V-E1. This procedure will maintain the system at a maximum temperature of 200°R. This system of cooldown has the advantage of utilizing the maximum latent and

sensible heat capabilities of the fluid hydrogen, and will provide relatively uniform temperatures across the diameter of the piping.

The procedure just described can be accommodated by the existing LH_2 piping systems through the addition of two 4" diameter vacuum jacketed by pass systems as follows:

1. Provide a 4" vacuum jacketed by-pass line from the suction side of the FTPA to the discharge side. A detail description of this minor addition to the vacuum jacketed piping is described in M-1 Criteria Change, M-1-1136.

2. Provide a 4" vacuum jacketed by-pass line from the vent system of vessel V-El to the discharge side of the vessel which will allow the cooldown procedure to proceed in either direction, from the vessel V-El through the system to the catch vessel V-E2, or in the opposite direction from V-E2 through the system to the run vessel V-El. This revision is described by M-1 Criteria Change M-1-1137[2]. Figure 2 is an isometric drawing of the large diameter LH_2 piping system. Existing systems are shown in heavy black lines and the supplemental piping required to implement effective cooldown is shown in dashed lines. Appendix A to this report entitled "Thermal Stress Analysis and Cooldown Procedures for LH_2 and LO_2 Systems", prepared by the Computer Sciences Division at Von Karman Center provides supporting calculations leading to the correlation of piping system temperatures vs. component stress and indicates the vent temperature which should be obtained prior to introduction of fluid to the system. As a part of the study, a computer program was set up to determine the time required to cooldown the discharge line from the TPA to the catch tank V-E2. Based on the

results of that study, it is estimated that overall system cooldown can be accomplished to a safe temperature for introduction of fluid within 24 hours after GH_2 cold gas venting is initiated. Calculations have been prepared which indicate that the bowing effect on the LH_2 pipe systems during controlled cooldown and during periods of standby will be minimized since the development of large thermal gradients across the diameter is prevented.

B. LO_2 SYSTEM COOLDOWN PROCEDURES

1. Purge vessel V-E10, run line to V-E14, V-E32 and V-E12; on-stand run vessels V-E12, V-E14 and V-E32; suction line to the OPTA and the discharge line from OPTA to V-E11 with GN_2.

2. Cooldown V-E10 or V-E11 and achieve a steady state vessel cooldown condition.

3. Pressurize vessel V-E10 or V-E11 to 100 psi with the liquid level at approximately the 1/2 point at 500#/hour.

4. Relieve cold GN_2/GO_2 mixture through the LO_2 pipe system either from V-E10 in the direction of normal flow or from V-E11 in the counter direction to normal liquid flow.

5. Regulate the rate of gas flow with Hammel-Dahl flow control valves to 7,000#/hour in the reverse direction of flow or 21,000#/hour in the normal direction of flow.

6. Flow cold gas through the piping system until a steady state exhaust gas temperature of 360°R is attained in the vent gas system after which the run vessel can be topped off and cryogenic fluid introduced to the piping system.

7. Since the LO_2 piping systems are not insulated, cryogenic liquid cannot be allowed to remain in the horizontal piping runs for long periods of time after the test is completed. Quick draining of the LO_2 piping systems will be required in order to prevent bowing of the large diameter piping due to warm-up of the outer wall and subsequent stratification of the contained fluid into vapor and fluid phases thus causing a non-uniform temperature distribution across the pipe diameter. Low point bleeds in the LO_2 piping system will be utilized to draw off liquid oxygen into portable tank trailers or for pumping back to storage. Warm gas purging or inerting of the large diameter partially liquid filled piping should not be permitted since this procedure could aggravate any tendency of the system to bow as a result of non-uniform temperature distribution across the pipe diameter. Appendix A presents studies which indicate that the uninsulated LO_2 system can be prechilled to 360°R in order that liquid can be introduced to the system without over-stressing of the associated components.

The procedure described for chilldown of the LO_2 piping system can be accommodated by the addition to the existing LO_2 piping system of one 4" diameter by-pass system described as follows:

1. Provide a 4" stainless steel by-pass line from the suction side of the OTPA to the discharge side. This by-pass line will be similar to the LH_2 by-pass line described in M-1 Criteria Change M-1-1136[1].

2. Provide a 4" stainless steel by-pass line from the vent of V-E10 to the discharge side of the vessel, similarly to the LH_2 by-pass described in M-1 Criteria Change M-1-1137[2].

C. THICKWALL CRYOGENIC VESSEL COOLDOWN PROCEDURE

Cooldown of the high pressure GGA LH_2 and LO_2 run vessels V-E9 and V-E12, will be accomplished by bleeding cryogenic liquid into the bottom of the vessels through the small diameter fill line until a pool depth of 1.8 feet is reached, after which filling should cease until the pool has flashed off. Repeat this procedure twice at 20-minute intervals after which the vessels may be filled at a rate of 500#/hour until they are filled. The vessel systems will require approximately 24-hours to reach steady state temperature conditions. Technical justification for the procedures recommended are presented in Appendix A of this report.

III. CONCLUSIONS AND RECOMMENDATIONS

Comprehensive temperature gradient determination studies and stress analysis of 18 and 20 inch diameter flanges during theoretical exposure to cryogenic fluids were reviewed by Aerojet. These studies are included as part of Appendix A, and they formed the basis for the conclusion that large diameter components of varying cross-section should not be shocked by direct contact with massive flows of cryogenic fluids. It was concluded that large diameter high pressure piping systems should be prechilled to a predetermined temperature prior to cold shocking with LH_2 or LO_2.

Based upon a thermal analysis of the LH_2 and LO_2 systems it was concluded that the necessary degree of prechilling can be accomplished by utilizing cold gas generated in the LO_2 and LH_2 off-stand run vessels.

It is therefore recommended that the necessary LH_2 piping system revisions, described in Reference 1 and 2, and LO_2 piping system revisions described in Section II-B of this report be approved. It is intended that current construction contracts for the LH_2 and LO_2 systems will be amended to incorporate the by-pass piping required to implement the cooldown procedure described under Section II, the technical section of this report.

IV. FIGURES

V. REFERENCES

1. M-1 Criteria Change M-1-1136.

2. M-1 Criteria Change M-1-1137.

VI. APPENDIX

A. APPENDIX A

(UNDER SEPARATE COVER)

AETRON A DIVISION OF AEROJET GENERAL CORPORATION

GENERAL TIRE

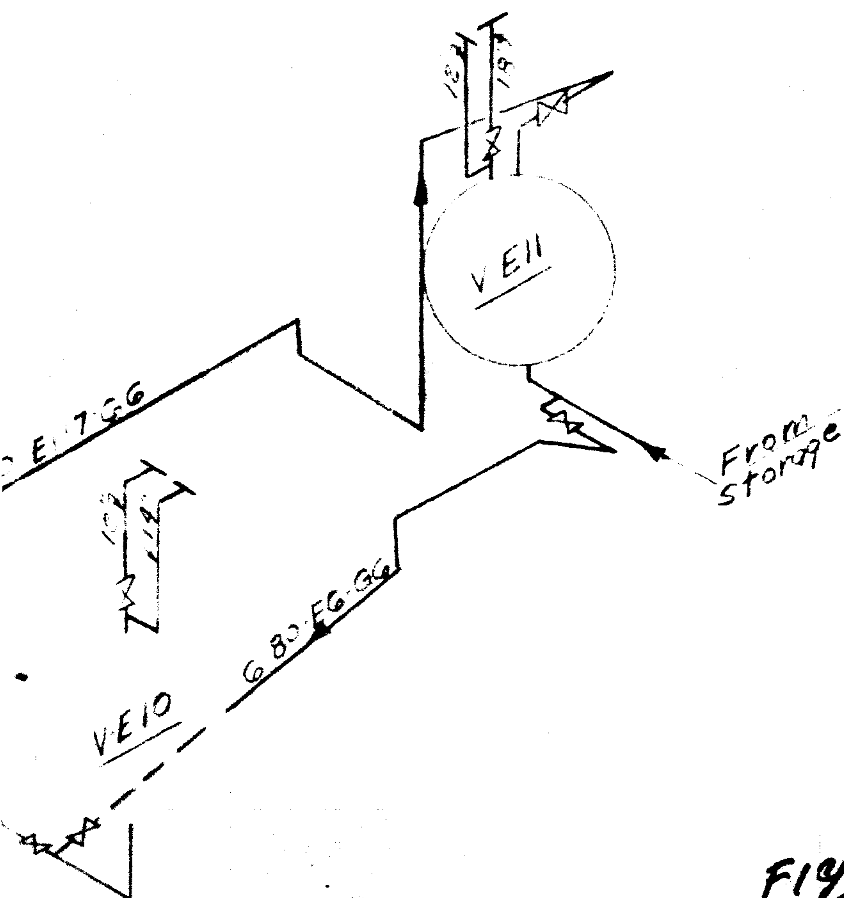
ISOMETRIC LO_2 SYSTEM

JOB M1 E AREA

FIGURE 2

DRAWN T. J. W DATE 11-20-63 PAGE ____ OF ____

CHECKED ____ DATE ____ DATE ____



LINE NUMBER As Noted

COMMODITY LIQ. OXYGEN

TEMPERATURE ____ °F

PRESSURE ____ PSI

GPM ____

VELOCITY ____ FT/SEC

SPECIFIC GRAVITY ____

VISCOSITY ____ CENTIPOISE

ALLOWABLE STRESS – PSI

$S_e = f(1.25\ S_c + 0.25\ S_H)$

$S_c =$ ____ PSI, $S_H =$ ____ PSI

$S_e = 1.0 (1.25 \times$ ____ $+ 0.25 \times$ ____ $)$

$S_e =$ ____

MODULUS OF ELASTICITY

OPERATING = ____ × 10 ____ °F

COLD = ____ × 10 ____ 70 °F

MODULUS OF LINEAR EXPANSION

OPERATING TEMP = ____ 0

MATERIAL –

A ASTM – ____ – ____

B ASTM – ____ – ____

WEIGHT OF PIPE

A SCH – ____ B SCH – ____

OUTSIDE DIAMETER, INCHES

A ____ C ____

B ____ D ____

THICKNESS, INCHES

A ____ C ____

B ____ D ____

ELBOW, FT

A ____ C ____

B ____ D ____

BOWING YES ☐, NO ☐

WIND LOAD YES ☐, NO ☐

SEISMIC LOAD YES ☐, NO ☐

WATER HAMMER YES ☐, NO ☐

VIBRATION YES ☐, NO ☐

COMPONENTS

SIZE	DESCRIPTION	WEIGHT (LBS)	TIME OF CLOSURE (SEC)

Fig 2 (2)